Recycling organic waste – effects on soil quality, plant nutrient supply and environmental impact

1. Introduction

"Waste should be considered a resource, and its management should be holistic and form part of integrated water resources, nutrient flow and waste management" (Water and Sanitation Collaborative Council, WSSCC, 2000).

Return of organic wastes to soil is a step towards more closed nutrient cycles, greater sustainability, and reduced environmental loads. The regulation on fertilizers of organic origin describes the allowed use of organic waste products in agriculture and in landscaping in Norway (Norwegian Ministry of Agriculture and Food 2003). The concentration of heavy metals in the organic waste is the main quality criterion according to the regulations. In order to judge how better use of organic wastes in agriculture and landscaping can be obtained, there is a need to quantify effects of such materials on plant nutrition and associated health and agronomical risks. In a long-term perspective, effects on soil fertility, included storage and turnover of added carbon (C) and nutrients and impacts on soil organisms and their activity, should also be considered.

Our current sanitation concepts are not designed to utilize the values of wastewater. The present use of sludge as soil conditioner is heavily questioned nowadays because of hygienic hazards associated with sludge use that may contain problematic substances such as heavy metals, pharmaceuticals and endocrine disruptors (Wilderer 2005). The biggest problem of treating wastewater results from the fact that potentially valuable substances are present in extreme dilution and mixed with all sorts of other substances. In Norway 25% of the population live in scattered areas where small on-site wastewater systems are widespread. Both in scattered populated areas and in more concentrated areas there is a potential to develop and implement environmentally sustainable systems which recycle a larger part of the resources from wastewater. Local loops are expected to give better control and improve wastewater treatment efficiency compared with conventional sewage systems.

The programme ORIO "Organic Waste Products and Recycling of Resources" (2001-2005), gave financial support to several projects on organic waste products, but not research projects. Therefore most of those projects were practical and developing work, reported in project reports rather than in scientific papers. Because the funding of research on organic waste in Norway has been limited, knowledge on these matters, relevant for the Norwegian society, is fragmentary and insufficient (Haraldsen et al. 2005). Nationally, scientific expertise on basic topics is available, but should be given sufficient funding in order to approach this complex field in the broad sense. Moreover, important questions related to the use of organic wastes are still unanswered, even internationally.

The intention of the proposed Strategic Institute Programme is to join and educate highly qualified scientific personnel in a move forward to answer basic questions related to recycling of organic wastes derived from the human society, using this resource in agricultural and urban greening areas environmentally safe in all respects.

Organic wastes differ in many respects and new types are constantly being produced. Thus, in this programme our main focus will be on issues of general importance. In particular, we will search for methods to determine á priori how a given waste affects plant nutrition, storage and turnover of added carbon and nutrients, how soil organisms and their activity are affected and environmental and health risks associated with its use.

2. State of the art

2.1 Ecological sanitation – recycling of resources in wastewater

Wastewater contains, besides noxious and hazardous matter such as pathogenic organisms, a variety of valuable substances including nutrients (N, P, K, etc) for fertilization (Johanson et al. 2001), fatty acids as raw material for industrial chemistry and organic matter as energy source. Two main

principles in ecological sanitation are the household centred planning approach and circular system of resource management. Systems based on source separation transform waste into valuable resources, such as fertilisers, soil amendments and bio energy (Skjelhaugen 1999, Ottherpohl 2000, Johansson 2001, Wilderer 2005). In a source separating sanitary system blackwater is diverted from the water cycle, thus reducing the risk of contaminating both surface and groundwater sources. Ecological sanitation enables 80-90 % of the nitrogen, phosphorus and potassium to be recycled (Vinnerås 2002).

Phosphorus adsorbed in wastewater filters designed for P removal can be a valuable fertilizer when the filters have been exchanged with new media (Jenssen & Krogstad 2002, Kvärnström et al. 2004). Our institute has been involved in research and development of filters designed for P removal in more than 15 years, but more knowledge is required concerning hygienization of used up filter media, their usefulness for application as a P source and implementation of such media on farmlands.

The approach in this program will have the basis in earlier research and development programs on ecological sanitation in Norway and Sweden (Gaut 1998, Johansson 2001). The development and implementation of environmentally sustainable wastewater technologies is an important and significant aspect for both developed and poor countries.

2.2 Plant nutrients in organic waste – content, storage and turnover

2.2.1. Nitrogen

The properties of organic waste differ enormously depending on the origin and the treatment of the wastes. The nitrogen (N) fertilizer effect of organic waste products varies considerably, e.g. from none effect of composted household waste both in the short- and medium term (Henriksen & Eltun 2002) to a considerable and rapid effect of meat bone meal (MBM) (Lundström & Lindén 2001, Jeng et al. 2004, Ugland et al. 1998).

Much current knowledge on both short- and long-term organic matter storage and turnover is integrated in dynamic, multi-compartmental decomposition models (e.g. Paustian et al. 1992, Henriksen & Breland 1999a). A major challenge is to find measurable criteria for distribution of C and N among different compartments (pools) (Paustian et al. 1997, Elliott et al. 1996). For short-term dynamics of readily degradable materials (e.g. crop residues), results from wet chemical analyses or near infrared reflectance (NIR) spectroscopy are applicable (Henriksen & Breland 1999b, Henriksen et al. 2003). In the case of partly decomposed, complex materials (e.g. composts), stepwise chemical digestion gives variable results (Asdal et al. 2002). For such materials, estimation of kinetically defined fractions, based on mineralisation rates under controlled conditions (Breland & Eltun 1999), may be an alternative or a supplement. Incubation under standardised conditions might serve as a bio-assay for determining fertiliser values of various wastes and thus provide information that is strongly needed in order to increase the use of organic wastes in agriculture. It is crucial that such a method is thoroughly tested under field conditions.

2.2.2. Phosphorus

Recycling of phosphorus (P) is an important topic as phosphate rocks are a limited resource. The sources are calculated to cover the demand for P in 150 to 400 years if the today’s level of winning is continued (Linderholm 1997). In Sweden, it has been suggested a long term objective to recycle 60% of P in sewage sludge to productive land by 2015 (Naturvårdsverket, 2002). It has been shown that a substantial part of organic farms in Norway have a negative P balance (Løes & Øgaard 1997; Haraldsen, et al. 2000). In the long run additional P inputs will be needed to ensure a satisfactorily P supply to the crop. Recycled organic waste products are valuable P-sources in agriculture and landscaping, and in accordance with the organic farming ideology (Stockdale et al 2001). Therefore, it is of great significance to evaluate the P fertilizer potential of different organic waste products, and carry out studies on the plant availability.

Phosphorus in organic waste appears both in organic and mineral compounds. In meat bone meal (MBM), which contains 40-50 g P kg^{-1}, P is partly related to the meat fraction, and mostly to the bone fraction as $Ca_5(PO_4)_3OH$. Jeng et al. (2004) found that P in MBM had significant effect on P uptake both the first and the following growing season, and unused P from MBM lead to increased levels of readily available P in soil. Kahiluoto & Vestberg (1998) found that P uptake from BM was significantly larger than the P uptake from crushed Kola apatite in a pot experiment. Furthermore, soil acetate-extractable P was significantly increased by BM, but was not influenced by Kola apatite. Baker et al. (1989) found considerable P-effect of BM in green house experiments. This indicates that BM is a better P source than the commonly used phosphate rock. pH is an important factor influencing P release from bone meal. Earlier investigations indicate that bone meal may have greater P fertilizer effect in acid soils than in soils with pH>6 (Bekele & Hofner 1993, Surendra et al. 1993). However, these investigations were carried out on tropical soils, and there is a need to study the P uptake from BM in different Norwegian soil types where each soil type is adjusted to different pH levels varying within the range recommended for cropping. In a Swiss study the average content of total P was found to be 3.4 g kg^{-1} dry matter in different composts from solid kitchen and garden wastes (Frossard et al. 2002). In these composts, on average 29.4 % of the total P was organic P. The inorganic P is present in different forms with different mobility (Traoré et al. 1999). 30–50 % of total inorganic P has been found as precipitated P-Ca compounds (Frossard et al. 2002) with pH higher than 7. In a pot experiment the utilization of compost P at the first cut of white clover was significantly related to the proportion in compost of P isotopically exchangeable within one minute (Sinaj et al. 2002). However, for the following cuts the proportion of organic P in the compost was positively related to the total utilization of compost P. This implies that both release from organic and inorganic P forms has to be considered when studying P release from organic wastes.

Use of Fe and Al for precipitation of P has produced sludge with very low P availability (Jokinen 1990, Cox et al. 1997, Ottabong 1997, Huang & Shenker 2004, Krogstad et al. 2005). Frossard et al. (1996) found that both the amount of soil available P and the origin of sewage sludge was important for P uptake by the crop. Biologically purification, without chemical additives, as well as lime treatment, resulted in sludge with a P fertilization effect comparable to inorganic P fertilizers (Krogstad et al. 2005). In order to improve recycling of P from sludge, the processes for waste water treatment should be taken into account.

2.2.3. Trace elements

Organic waste may also be of importance for supply of trace elements as copper, zinc and manganese to plants. Deficiency of trace elements is locally a problem in Norwegian agriculture, and generally in organic farming. In a survey at organic farms, most of the plant samples from dairy farms had concentrations below 20 mg Zn kg^{-1} dry matter plant material, the suggested critical plant concentration for normal plant growth. The Cu:Mo ratio found in the herbage was generally low, 73 % below 6 (Govasmark et al. 2005a,b), which is the lower level for the dietary need for ruminants. Organic waste with low content of mercury, lead and cadmium, but considerable content of copper, zinc and manganese can improve the supply of these elements in poor soils, and should therefore be investigated.

2.3. Organic waste and soil improvement

Organic waste influences soil quality in many respects. Generally addition of organic matter to soil improve soil structure and physical properties, but this effect is related to the properties of the organic matter itself and how soil organisms transform the organic matter (OM) in the soil. Application of compost may decrease crust formation and runoff due to stabilization of soil aggregates (Bresson et al 2001). Because the easy biodegradable part of OM and available nutrients vary between different waste types, the effects on physical and biological properties of the soils are variable. Content of heavy metals and organic pollutants in the organic waste may influence the biological processes in transformation of OM.

Some organic waste types have been found to influence essential soil organisms. Addition of meat and bone meal (MBM) to soil increased potato quality due to reduced incidence of potato scab (*Verticillium dahliae*) and decreased populations of parasitic nematodes (Lazarovits et al., 1999; Lazarovits, 2001). Earthworms play a central role in decomposition of organic waste, either as vermicomposting (Tognetti et al. 2005), or after the application of organic waste to the soil (Schonbeck & Evanylo 1998). Earthworms may have strong influence on nematode densities and nematode trophic structure during decomposistion of organic waste (Domingues et al. 2003). The number and species of earthworms may increase after application of sludge or other organic waste (Piearce & Boone 1998, Piearce et al. 2003), leading to increased formation of biogenic soil structures (Jongmans et al. 2003). Studies of earthworms and soil structure in relation to utilization of different types of organic waste are therefore highly relevant.

The reuse options and effect of filter media in wastewater filters consisting of natural soil, lightweight aggregates or shell sand saturated with P and other nutrients have so far not been evaluated in Norway. These filters may in few years represent large potential waste problems if alternative uses and potential for recycling nutrients are not better evaluated.

2.4 Effects of organic waste on runoff and leaching

Application of different organic waste types on soils has been reported to cause varying effects on soil erosion, runoff, leaching of plant nutrients and spreading of organic pollutants. Norwegian studies on these topics are however limited. Njøs & Hove (1984, 1986) found that application of 50 tonnes DM ha^{-1} sewage sludge to loamy clay soils effectively reduced the erosion when the sludge was not mixed into the soil. Mixing the sludge into the soil gave less reduction in erosion. Skøien (1989) found increased level of phosphate P in runoff from plots with sewage sludge used as soil conditioner without deep incorporation compared to conventional tillage. In a study of leaching of N and P under outdoor storage of sludge, Ekeberg (1991) found that half of the amount of N was lost after one year, while the P loss was very small. In a study of sewage treatment processes on plant availability of both sewage sludge and soil P, Krogstad et al. (2005) found low concentrations of water extractable P in soil after sludge application. However, considerable increase in inorganic P took place in the soil (50-90%) and they concluded that this accumulation must be considered as a potential environmental risk due to the possibility of soil erosion.

Quilbe et al. (2005) found that the concentration of ammonium-N and particulate P in runoff varied between different sludge types. Hodgkinson et al. (2002) found that use of maximum recommended levels of different organic wastes as sewage sludge, farm yard manure and P-fertilizer did not significantly increase P losses in any drainage season. Shober & Sims (2003) found that there is need for comprehensive environmental risk assessment of biosolid P, because the current N-based approach to biosolids does result in increases of soil P. Mobilisation of N and P in runoff after organic waste spreading is likely to contribute to eutrophication of water bodies, but still the processes involved and the factors that influence these processes are still not fully understood (e.g. Vanden Bossche et al. 2000 and Quilbe et al. 2005). Because of few relevant studies from Norway, research is needed on the potential for loss of P to water bodies from organic waste.

3. Objectives

3.1 Main objective

Increase the knowledge about sustainable and environmentally safe use of organic wastes as fertilizers and soil amendments in agriculture and landscaping.

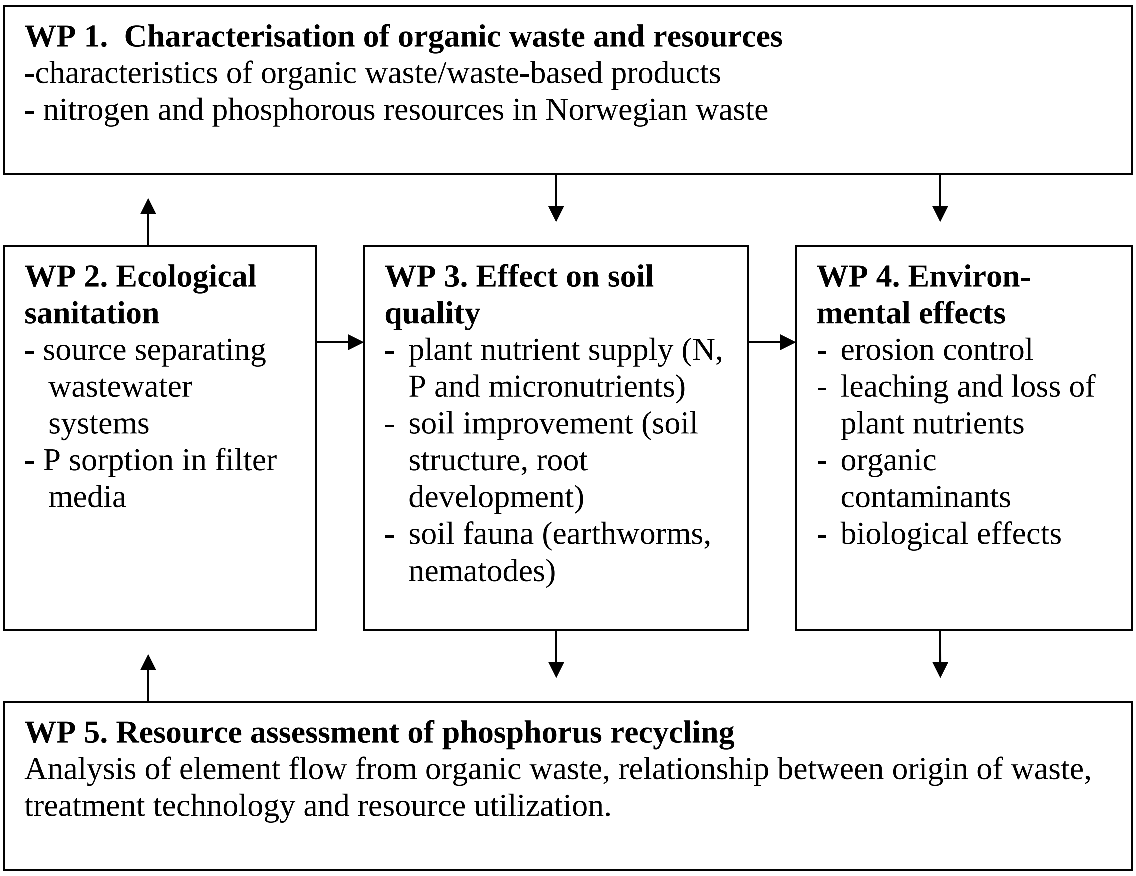
3.2 Secondary objectives

- develop methods for: 1) determination and improvement of P availability for plant growth using organic waste products, and 2) evaluation of the potential of different organic waste products as P source in agriculture and landscaping

- perform tests of different treatments of organic waste and waste water in order to improve the reuse of P
- develop new knowledge on how various types of recycled organic wastes affect turnover of organic C and N in soil
- determine effects of different organic waste types on soil erosion control, leaching and loss of plant nutrients and organic pollutants to water bodies
- perform resource assessment on organic wastes, and determine criteria for optimal use of the different fractions of organic waste products in agriculture and landscaping.

4. Description of the research programme

The research programme will be organized in five work packages (WP1-5). Special emphasis will be made on phosphorus, and processes on P related to organic waste will be studied in all WP's.



4.1 WP 1. Characterisation of organic waste products

General properties of different organic waste types, as sewage sludge and waste derived products as compost, are partly documented through the ORIO programme and other sources. The documentation is fragmented, there is no general representation of the material and documentation of properties of waste is partly lacking.

<u>Aims of the studies</u>

Make a comprehensive representation of characteristics of organic waste/waste-based products and an overview of nitrogen and phosphorous resources in Norwegian waste.

<u>Methods</u>

Existing documentation properties of organic waste and waste derived products will be collected and missing documentation identified. Characterisation of waste types and waste-derived products will include parameters relevant for both treatment options and end use options. Existing documentation will be supplemented with chemical analysis with lack of information.

An analysis of material flow of organic wastes will be based on available data. Waste fractions, including both solid and liquid fractions, will be defined by sources (industry, service, households, sludge etc.) Obtained information will be spot checked against direct information from waste generators and missing data will be obtained in relevant analyses. On the basis of material flow data and characterisation data there will be possible to identify and characterise the most important P and N containing waste streams. The result will be used as an input to select the most important waste types for further studies in WP 3, 4 and 5.

Timetable for activities in WP1.

Activities	2006				2007				2008				2009			
Detailed planning	x	x	x													
Characterization of waste types		x	x	x												
Map of waste streams			x	x	x	x										
Identification of P/N waste resources					x	x										
Publication					x	x										

4.2 WP 2. Ecological sanitation – recycling of resources in wastewater

In the last decade new sustainable resource recycling sanitation systems have been available. Ecological sanitation is an approach based upon three fundamental aspects: sanitizing human excreta, preventing pollution and recycling excreta nutrients for soil quality and agricultural purposes. Such sanitize- and recycle approach can be based on source separation in which domestic waste is split into greywater (water from sinks, showers and laundry machines) and blackwater (faecal matter and urine form toilets), facilitation recycling and providing more sustainable solutions for domestic waste than conventional systems. This split of the domestic waste represents respectively the *water loop* and the *nutrient & energy loop* and the new technology close these loops.

Aims of the studies

Ecological sanitation has a potential to reduce health risks, improve access to water and recycle nutrients back into agriculture, both in developed and poor countries. This represents an important contribution to meet the UN Millennium Development Goals regarding poverty and hunger reduction, sustainable development by e.g. improved access to safe drinking water (www.un.org/millenium/declaration). In these WP different technologies facilitating reuse of resources from wastewater will be evaluated under Norwegian conditions (cold winter climate and relative short growing seasons):

1. Source separating wastewater systems

- Toilet wastewater - evaluation and development of composting systems which are both environmental and user friendly, have less odour and give a better (sanitary safe and higher availability of plant nutrients) compost products than the systems available today.
- Reuse of urine – separation systems, storage, use and hygienic risks
- Greywater - treatment evaluation and optimal design in different scales

2. P sorption in filtermedia

- Evaluation and test of filter media and filter design for optimal P removal
- Evaluate reuse of P in P rich filter media and sediments (WP 3)

Working hypotheses

- Separation of toilet wastewater can offer an attractive way of approaching to the sustainability. Besides it can also give products more suitable as fertilisers for agriculture than present conventional wastewater systems.

- Dry toilets can be enhanced in cold climate regions with vermicompost and improved design of container as well as better operation and maintenance.
- Filtermedia can be designed for high P removal by sorption and used filtermedia have a value as fertilizer for agriculture.

Methods

The dry matter content in toilets is normally less than 1%. As a consequence some organic matter must be added in order to achieve appropriate treatment of black water by e.g. liquid or dry composting. Vermi composting utilises worms to enhance the composting process by concentration the nutrients into vermin-casts and worms. Grinded organic household waste, animal manure or residues from food processing are all additives that can be used for successful composting. Anaerobic processes are attractive because the methane (biogas) produced has higher energy value than thermal energy from a liquid composting process. Efforts need to be made to develop anaerobic reactors on smaller scale for cold climates. The challenge is to produce hygienic safe product from human wastes which is odourless, and where the nutrients are conserved. There is a large menu of dry toilets with different types of composting processes handling the excreta waste, but most systems have problems with limited capacity, odours and wet compost of insufficient quality. These in turn make the composting processes slow in cold climate areas. There is a large potential to improve these systems and adapt them to be environmental sustainable. Using of organic household wastes and natural available materials, e.g. cones or bark (as bulking agents for proper decomposition of organic waste materials) could be implemented. Quality tests and hygienic risk analyses will be carried out in laboratory.

Greywater treatment constitutes an important aspect of ecological sanitation. Available systems will be investigated and evaluated. The research challenge is to make the systems smaller with a high and stable removal of pathogens and organic matter. The existing performance data will be input to mathematical modelling of optimal design.

Urine normally needs storage and dilution before it is approved as a hygienic acceptable fertiliser. Today many manufactures deliver urine diverting toilets that can easily be retrofitted into existing or new buildings, making urine collection possible. The combination of local treatment and handling of waste by farmers will be evaluated in the project in different scales: Single residence (5 PE), small group of residents (50 PE) and cluster scale (200-500 PE) with blocs forming a local neighbourhood. Bioforsk, Soil and Enviroment Division is involved in designing and building of the test locations which are planned be established in near future at Ramme farm in Vestby and Øverland farm in Bærum. In addition the campus of the Norwegian University of Life Sciences (UMB), that cooperate with our institute, will implement source separating wastewater systems in the next years. Moreover investigations will be carried out on existing systems in order to advise, consult and guide other projects focused on urine separation, collection and reuse. Hygienic risk will be tested in laboratory within different sorting systems and storage conditions (e.g. temperature and time). Use of urine as fertiliser will be evaluated in WP3. Acceptance of urine sorting toilet systems will be evaluated by surveys and questionnaires.

Different filter media, such as lightweight aggregates, shell sand and natural Fe/Al rich soil in addition to P rich sediments, used for wastewater treatment in existing on-site systems and adapt to trap P will be tested. These media will be evaluated as fertilizers in agriculture by field investigations and laboratory tests in WP 3. Content of heavy metals, organic pollutants and faecal indicator organisms in the filters and detrimental effects of these compounds will be evaluated by ecotoxicological and microbial standard tests in WP1.

Deliveries

Improved knowledge of wastewater resources and optimal handling of these constituents. Technical reports as basis for technical guidelines on source separating wastewater systems at different scales. Improved design of Norwegian composting toilets. Improved sustainability of sanitation systems.

Timetable for activities in WP2.

Activities	2006				2007				2008				2009			
Detailed planning	x	x														
Source separating toilet systems		x	x	x	x	x										
- dry toilet composting systems		x	x	x	x	x	x	x								
- reuse of urine		x	x			x	x		x	x	x					
- greywater treatment				x			x				x					
P sorption in filtermedia		x	x			x	x			x	x		x	x		
Publishing						x					x	x	x	x	x	x

4.3 WP 3. Effects on soil quality

Different organic waste materials will be evaluated with regard to release of plant nutrients, and effects of soil structure and soil organisms. The study includes evaluation of P release from both inorganic P compounds and organic P in waste products.

<u>Working hypotheses</u>

- Short-term incubation performed at elevated temperature in the laboratory can serve as bio-assay for determination of waste-specific N fertilizer effects that are relevant under field conditions.
- Partly decomposed, complex wastes (e.g. compost) mainly adds to a medium-term soil organic matter pool (half-life ≈ 20 years), the accumulation of which contributes significantly to plant nutrition and maintenance of soil organic matter, but also to potential off-season losses of N.
- Better chemical extraction procedures more correlated with the plant available P content of organic waste products can be developed.
- Composting will generally increase plant availability of P in MBM.
- Composting in presence of earthworms will increase the P release from MBM and organic P compounds relative to composting without earthworms.
- The effect of organic waste products on earthworm populations are mainly related to the feeding value of the waste, and less due to content of potential harmful substances.

<u>Laboratory methods</u>

We aim at developing a rapid bio-assay indicating N fertiliser effects over about two growing seasons in the field. As a starting point, a series of incubations will be performed in the laboratory. A broad collection of organic wastes, expected to represent different C and N mineralisation patterns, will be subjected to chemical analyses, NIR spectroscopy and paper chromatography before incubation under various conditions in terms of temperature (–5 to +30°C), soil (type and cropping history) and pre-treatment. Initial chemical composition, NIR spectra characteristics and C and N mineralisation results will be used to initialise and calibrate a multi-compartmental decomposition model (Henriksen et al. 2003) (possibly after modification), in an attempt to simulate N mineralisation throughout the incubation period (250 days) and potential fertiliser value under field conditions. Validity of bio-assay results and model simulations under controlled and field conditions (see below) will be investigated.

Nutrient content and availability in the compost may vary between composting plants and from year to year. Therefore, it is a need to develop a simple and reliable method of characterizing the P availability of compost. At present the AL-method (extraction with an ammonium-acetate-lactate solution with pH 3.75 (Egnér et al. 1960) and the CAT-method (extraction with 0.01M $CaCl_2$ + DTPA, pH 2.6 (CEN/TC 223 N 217, 1999) are used for characterizing organic fertilizers, but there are no experimental results revealing the relation between extracted nutrients and plant uptake. Organic waste products will be analyzed with both the AL- and CAT- method in addition to other methods commonly used for characterizing P availability in soil (e.g. P-$NaHCO_3$ and P-$CaCl_2$). The

sequential extraction procedure developed by Hedley et al. (1982) will also be considered. Moreover, evaluation of different relevant P extraction methods will be a part of the project. The results from the different P analyses will be correlated to plant P uptake to find the method best esimating the available P content of the waste product.

Crop experiments

Because organic waste contains macro- and micro nutrients in varying concentrations, it is difficult to isolate effects of each plant nutrient. In studies of P-effects it is therefore important that supply of N and other plant nutrients is not growth limiting, as shown by Jeng et al. (2006). The experiments will be coordinated between the WPs, as both P and N dynamics in soils are influenced by physical, chemical and biological factors. Therefore there is a need for testing of growth response using various types of waste in different soils. Soils with different properties (texture, org. C, pH, P-status, and cropping history) will be selected for experiments in laboratory, greenhouse and out-door environment (pot and field scale). The same soils will be used for evaluation of fertiliser effects of different organic waste types (N, P), and for studies of biological effects on processes in soils and soil organisms. This approach will enable a study of both N and P effects under similar growing conditions, and perform evaluation of N and P effects related to certain organic waste types. The experiments crops will represent different nutrient uptake and root system. Laboratory, pot experiments in greenhouse and out-door, and field experiments will be performed. Experiments on P-effects of MBM in greenhouse and field on different soils (Jeng et al. 2006), will be continued for evaluation of long-term effects.

Compost types for the experiments (pile-, reactor-, vermicomposting) based on different mixtures of organic waste will be made for use both in WP 3 and WP 4. The composting will be studied to determine which how different factors (e.g. aerob vs. anaerob composting, temp. digestion by earthworms) influence the changes in P and N availability of organic wastes.

In order to investigate the effects of different organic wastes on supply of Zn, Cu, and other trace elements, pot experiments will be performed using selected soils from areas where deficiency occur. In these experiments the supply of macronutrients has to be controlled by supply of inorganic fertilizer, and compared with use of equal amounts of micronutrients in inorganic form. Field experiments with use of organic waste with positive effects on micro nutrient supply will be carried out on organic farms.

The effect of organic waste products on earthworm populations will be examined in both pot experiment and field trials. Organic waste products will be mixed with soil in pots inoculated with commonly occuring earthworms in cultivated soils (e.g. *Lumbricus rubellus* and *Aporrectodea caliginosa*). Borrowing and casting activity will be recorded by computer aided tomography (Joschko et al. 1993) at different stages after mixing in organic waste. Species composition, numbers and biomass of single species will be recorded at end of the experiments. The impact of earthworm species on decomposition of most common organic waste products will be studied in field experiments both in agriculture and landscaping. Studies of soil structure, biopores and nematodes will be integrated in the earthworm studies. Increased knowledge of earthworm biology related to both agricultural and urban greening use of organic waste will be an important additional outcome of these studies.

Commonly recommended soil quality indicators (e.g Doran and Parkin 1996, Oades & Walters, 1994) include microbial indicators like microbial biomass, potential N mineralization, phosphatase activity, soil respiration etc. Although there is still no consensus on the use of soil biochemical properties (Gil-Sotres et al. 2005), such indicators will considered included in the work in order to determine status of the important microbial status of the soils.

Timetable for activities in WP 3.

Activities	2006				2007				2008				2009				2010			
Detailed planning	x	x	x																	
Collection of wastes and soils		x	x	x	x	x														
Chemical and spectroscopical analyses				x	x	x	x													
Incubation studies					x	x	x	x	x	x	x	x								
Evaluation of P-extraction methods		x	x	x	x	x	x	x	x											
Methods for increased P-availability					x	x	x	x	x	x	x	x	x	x	x	x				
Mesocosm and field studies		x	x			x	x			x	x			x	x					
Earthworm investigations		x	x			x	x			x	x			x	x					
Publishing										x	x	x	x	x	x	x	x	x		

4.4 WP 4. Environmental effects

In WP 4 environmental effects related to use of organic waste products will be examined. Design and establishment of experiments, selection of organic waste products will be based on input from WP 1-3.

The aims for the studies are:

1. Determine environmental effects from use of organic waste with different availability of plant nutrients (e.g sewage sludge or recycled filter medias), in different amounts relevant to agricultural areas and urban green areas. a) runoff and losses of nutrients (e.g N and P) and biological effects of contaminants in the wastes, b) reduced erosion caused by improved soil structure (mulching/incorporation).

<u>Methods</u>

1. Runoff measurement (plot and field scale) will be carried out. Various types of wastes will be applied in different amounts and with different types of incorporation into the soil. Experiments will be instrumented for runoff measurements and water sampling with focus on event studies. Experiments will, if possible, be located to existing sites where erosion studies already are performed. For urban green areas localities used in the ORIO project “Sludge and compost in urban greening” will be used.
2. Biological effects will be studied in lab experiments. A suite of relevant ecotoxicological tests will be performed with pore water from experiments with organic waste products. Pore water samples will be collected several times throughout a year to represent variations in bioavailability of harmful substances, due to seasonal changes in climate. The pore water approach ensure a worst case scenario in terms of concentrations of substances in the investigations. This is of great importance, especially when testing for mutagenic effects. Two different tests for mutagenic activity will be applied, both using induction of the cells own repair system for mutations (the so called SOS system), as a measure of genotoxicity. The two different tests differ in what microorganism they use. Because sensitivity might vary between species, more than one type of microorganisms should be used. Also, tests measuring general toxicity at three taxonomic groups will be applied. A nitrification test, a growth inhibition test with the water plant duckweed (*Lemna minor*), and a toxicity test with a water flea (*Daphnia magna*).
3. Lab experiments will be used for process studies of effects of freezing/thawing cycles, water saturation (changed redox) on stability and availability and leaching of nutrients from different types of organic waste.

Timetable for activities in WP 4.

Activities	2006				2007				2008				2009			
Selection of organic waste (WP 1- 3)	x	x														
Establish runoff experiment			x			x										
Measure environmental effects				x	x	x	x	x	x	x	x	x	x	x		
Lab experiment- freezing/thawing								x	x			x	x			
Lab experiment- biological effects			x	x				x	x	x						
Evaluation, recommendations, input WP 5											x	x	x	x		
Publishing													x	x	x	x

4.5 WP 5. Resource assessment of phosphorus recycling

The current perception of resources in organic waste is linked to energy, inorganic nutrients for plants and soil organisms, and organic material as soil conditioner. The energy is mainly utilised via incineration of waste or combustion of methane gas produced during anaerobic transformation of organic material. As natural mineral phosphate resources decline, the need for efficient use of alternative phosphorus sources increase. Waste is a potential phosphorus sink. Total amount of phosphorus applied to agricultural land in Norway is approx 25 000 tonnes/y, whereof 50% is mineral fertilizers, and 50% manure. This WP will focus on questions related to whether waste recycling can contribute to future supply of nutrients to bioproduction.

<u>Aims of the study</u>

This WP aims at determining whether waste recycling significantly can contribute to future supply of phosphorous to bioproduction. The objective of this work is furthermore to increase knowledge on element flow and know-how related to improved and sustainable use of P- resources in waste. The results are expected to clarify the role waste management can play in agriculture. The work will account for the amount of phosphorus in waste streams and how it relates to anthropogenic flow of P in the environment.

<u>Methods</u>

The estimated P flow will be based on outputs from the other WPs in this programme. The study should include all P in the bioproduction system, and system boundaries will be defined. Focus on the whole antrophogenic P-flow allows evaluation of whether waste is a significant P sink that can be considered as a future resource. The survey should furthermore determine which waste fractions that represent the largest P resources (both total and bioavailable). The anthropogenic N cycle in Norway has previously been presented by Bleken & Bakken (1997), and a similar approach will be used in this study. However, while Bleken & Bakken focused on commodities present in Norway, the present work will be focused on P in waste.

Topics:
Based on input from WP 1 and WP 3, the availability of P in the main flows will be estimated and evaluated (For example: sludge –high content, low availability).

1. Based on experiments in WP 4, recommendations on use of sewage sludge and other organic wastes, related to landscape elements and high risk areas, will be made.
2. Estimation of potentially available P and N-resources in wastes and after different treatments. Based on results from WP 1 and WP 3 evaluate commonly used treatment practices and use of wastes with regard to P-availability. Estimate potentially available P in waste based on different treatment scenarios. Scenarios should include alternatives based on present trends in choice of treatment and on technologies optimizing P-availability.

3. The rationale for waste as a potential source of P in sustainable agriculture. Collection of data on total P input to the bio production system. Evaluation of waste-P in relation to total mass inputs.

Timetable for activities in WP 5.

Activities	2006				2007				2008				2009				2010			
Detailed planning							x	x												
Collection of statistical data							x	x	x	x										
Evaluation and analysis											x	x	x							
Publications													x	x	x	x	x	x		

5. Project organisation and competence

The proposed research programme will involve all research divisions at Bioforsk, Soil and Environment Division, Ås (previously Norwegian Centre for Soil and Environmental Research (Jordforsk)). There is cooperation with Bioforsk, Organic Food and Farming division (previously Norwegian Centre for Ecological Agriculture (NORSØK)) on organic waste acceptable for use in organic farming. There is also cooperation with Norwegian University of Life Sciences, Department of Environment and Plant Sciences for education of a Ph.D student.

Project coordinator and leader of WP1 and WP3: Dr. Trond Knapp Haraldsen, key competence: earthworm ecology in cultivated soils, drainage and cultivation of peat soils, leaching and runoff from agricultural areas, organic cropping systems, organic waste products and animal manure, processes related to air and water movement in soils, soil mixtures for urban greening, soil morphology.

Leader of WP2: Section head, dr. Trond Mæhlum, Natural purification systems technology.

Leader of WP4: Section head, dr. Lillian Øygarden, Watershed management, soil erosion

Leader of WP5: Section head, dr. Roald Sørheim, Waste and toxic pollutants, soil microbiology

In WP 2 there is established cooperation on ecological sanitation with the Norwegian University of Life Sciences (UMB), Dept. of Mathematical Sciences and Technology (Prof. Petter D. Jenssen). UMB is recognised as a leading international centre of knowledge of ecological sanitation and is at the forefront of scientific developments in its field.

A reference group for the project will be established in order to keep contact to organisations representing producers and users of organic waste (Waste water treatment organizations, Norsk protein AS, Organisation for landscaping and urban greening, Norwegian Food Safety Authority, Norges Vel, and farmers organizations).

6. International cooperation

In WP 3 there is established cooperation on utilization of P from different organic waste products with Swiss Federal Institute of Technology (ETH), Institute of Plant Sciences, Group of Plant nutrition (Prof. dr. E. Frossard), Eschikon-Lindau, Switzerland.

7. Budget (NOK 1000)

Activities	2006	2007	2008	2009	2010
Programme coordination	150	100	100	100	
WP1 Characterisation	400	150			
WP2 Ecol. sanitation	400	450	400	400	
WP3 Soil quality	950	1000	1000	1000	110
WP4 Environment	500	500	500	500	
WP5 Resource assessment		200	400	400	115
Sum	2400	2400	2400	2400	215

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